

[54] **METHOD OF AND APPARATUS FOR CONTROLLING THE OPERATION OF GAS COMPRESSION APPARATUS**

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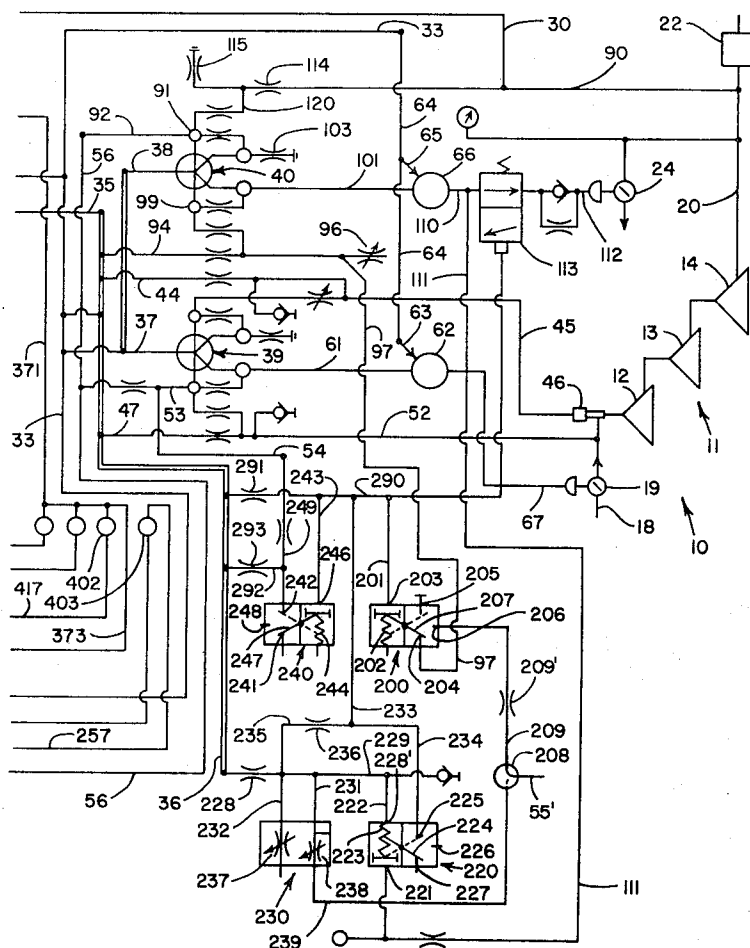
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[57] **ABSTRACT**

A control system for regulating operation of gas compression apparatus operable on base mode. The discharge pressure of the gas from the compression plant is sensed and a signal related thereto is compared to a predetermined signal to produce a resultant control signal, operable to modulate a dump valve which governs the venting of excess discharge gas to the atmosphere. When the magnitude of the resultant control signal reaches a predetermined value, a second control signal is transmitted to cause the dump valve to assume a fully open position. The second control signal also causes a valve regulating flow of gas to the inlet of the compressor to assume a fully closed position. The compressor is thereby in an idle state.

6 Claims, 3 Drawing Figures



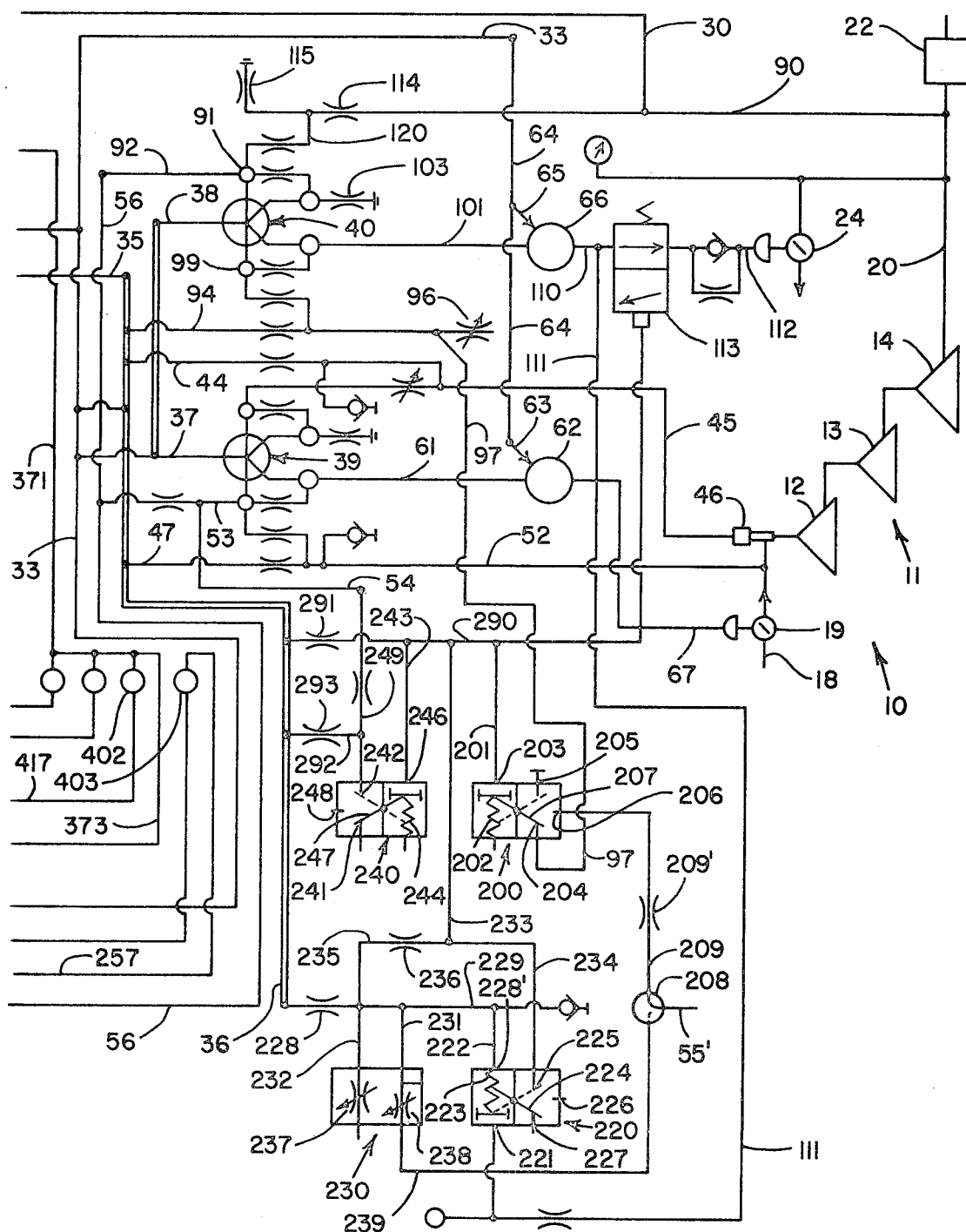
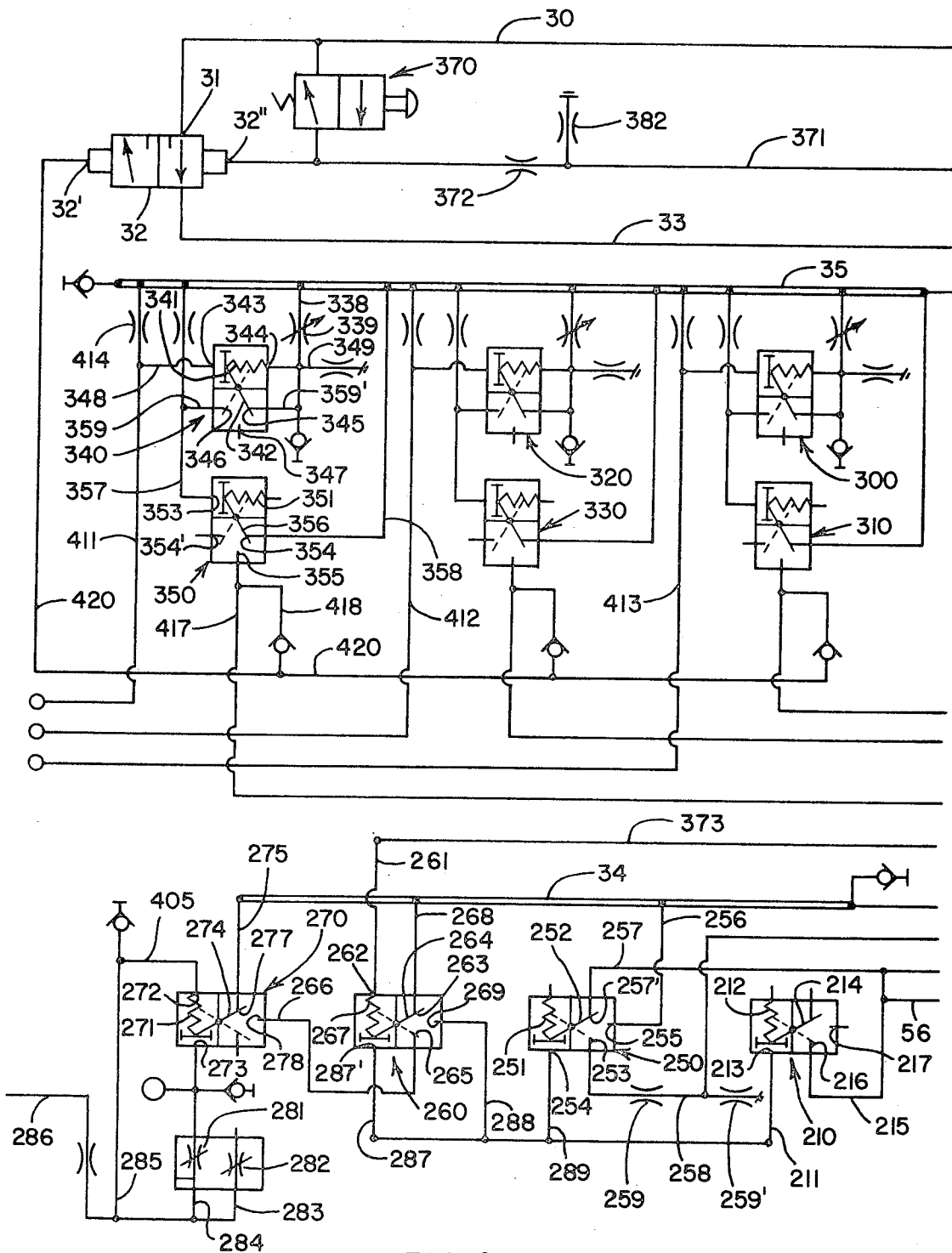


FIG. 1

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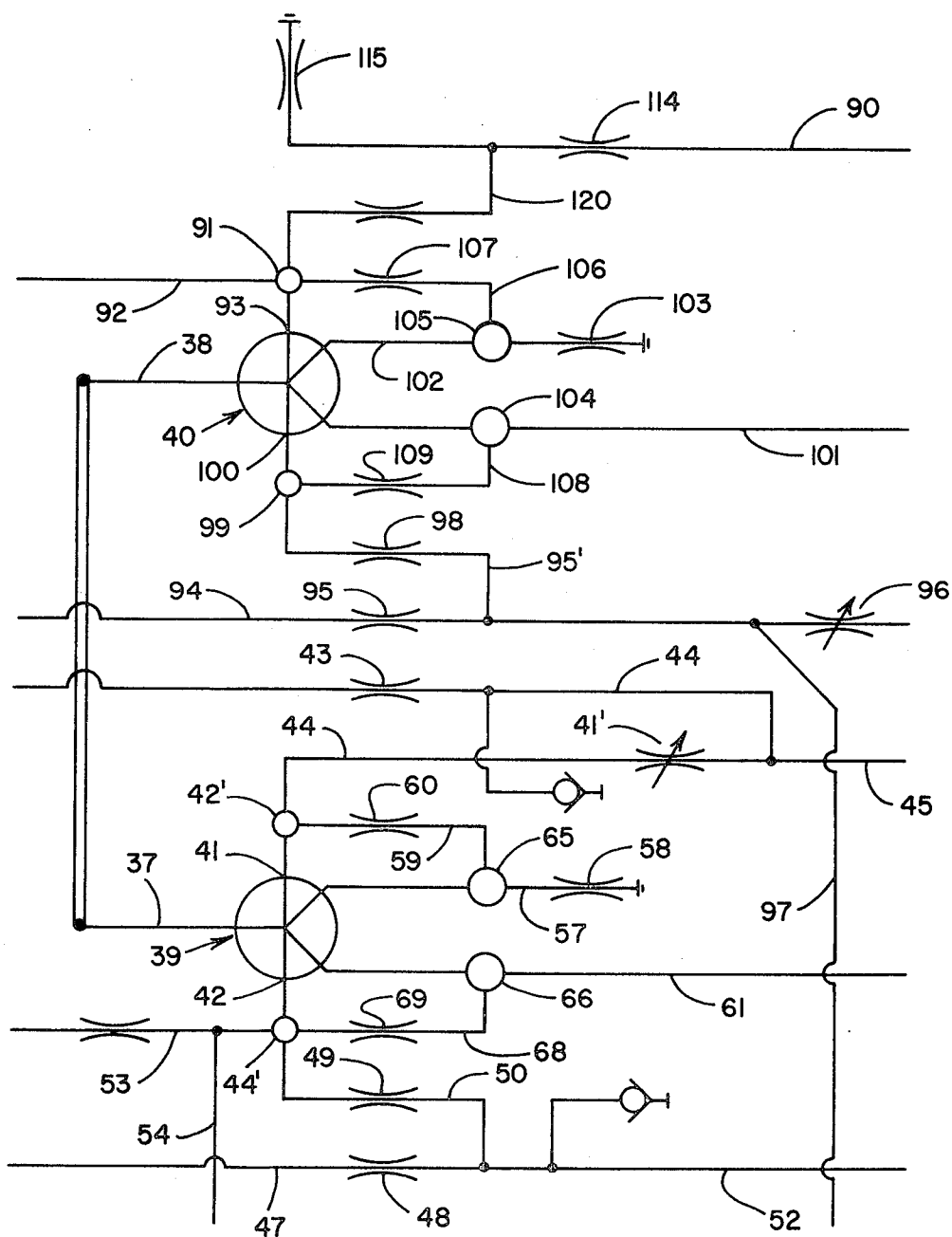


FIG. 3

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METHOD OF AND APPARATUS FOR CONTROLLING THE OPERATION OF GAS COMPRESSION APPARATUS

BACKGROUND OF THE INVENTION

In gas compression equipment, such as air compression apparatus employing a number of air compressors or air compression stages, wherein ambient air is compressed and delivered to a reservoir or storage vessel, for use at a variable rate, there are two general types of operation involved. The first type of operation is called base load operation. The compressor is controlled so as to deliver an output of compressed gas substantially consistent with a demand, variable within predetermined limits. As the compressed gas requirements decrease, a dump or bypass valve disposed in communication with the discharge conduit of the compressor will operate to vent the excess capacity to the atmosphere. The dump valve will be modulated to maintain the desired discharge pressure. The second type of operation is called intermittent load operation. When operating on intermittent load, the compressor will either be delivering full capacity to the plant with the dump valve completely closed or will not be delivering any compressed gas to the plant, with the dump valve completely open. With intermittent mode operation, there is no modulating the dump valve as done when operating on base mode.

During base load operation, if the load on the compression plant decreases substantially for a period of time, the bypass or dump valve will be open for a prolonged period of time to vent the excess discharge capacity to the atmosphere. Such venting operation substantially decreases the overall efficiency of operation of the compression equipment by maintaining the operating costs at such times equal to the costs when the load on the equipment is materially higher.

It is therefore an object of the invention to provide a novel control system to place compression equipment operating in base mode in substantially an idle state when the load on the equipment falls below a minimum predetermined point.

SUMMARY OF THE INVENTION

This invention relates broadly to the control of the operation of gas compression apparatus and more particularly to gas compression apparatus of the type employing a multistage axial or centrifugal compressor driven by a prime mover. Still more particularly, this invention relates to a control system for use in gas compression apparatus operable to place the apparatus in an idle state if the load on the apparatus falls below a predetermined point, when the apparatus is operating on base mode.

The control system includes means for sensing the pressure of the discharge from the compression apparatus and for sending a first signal related to the sensed pressure. First means are provided for receiving the pressure signal and for also receiving a first predetermined reference signal. The last mentioned means is further operable to transmit a resultant signal which is directly related to the pressure and predetermined reference signals.

The resultant control signal is transmitted to the bypass valve, to modulate same to maintain a substantially constant discharge pressure. The resultant control signal is also transmitted to second means, and

when the magnitude of the control signal has reached a predetermined value, said second means transmits a second control signal to cause the bypass valve to fully open and the inlet valve regulating the flow of air to the inlet of the compression apparatus to close. The gas compression apparatus is placed in an unloaded state.

When the second control signal is transmitted to the bypass valve and the inlet valve, valve means is actuated to prevent the concurrent transmission of the first resultant control signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 of the drawings illustrates in schematic a first portion of the control system of my invention;

FIG. 2 illustrates in schematic a second portion of the control system forming a continuation of the first portion; and

FIG. 3 illustrates a fragmentary view of the upper left-hand portion of FIG. 1, enlarged in the interests of clarity.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawing there is shown a gas compression system embodying the novel control.

The gas compression system 10 includes an air compressor 11 for the purpose of providing compressed air to a storage vessel or reservoir for use with pneumatic machinery, or similar applications where compressed air is utilized as an energy source. It will be appreciated there are many installations requiring compressed air in such large quantities that it is necessary to supply an air compression plant utilizing a multistage axial or centrifugal compressor which is represented by numeral 11. Compressor 11 may have any number of desired stages to obtain the requisite quantity and pressure of air. For the purpose of illustrating a representative machine, compressor 11 has three stages respectively, 12 which is the first stage and is in series with a second stage 13, and a third stage 14. Compressor 11 is driven by a prime mover, such as an electric motor, which is not shown. It should also be understood, intercoolers may be employed between the several stages as required to limit the temperature increase of the compressed air.

Inlet line 18 is provided to admit ambient air through an inlet throttle valve 19 to first stage 12 of compressor 11. Compressed air is discharged from the last stage of the compressor via discharge conduit 20 into storage tank or reservoir 22. A suitable compressed air discharge line (not shown) distributes air from reservoir 22 to desired locations at which it is employed.

In order to maintain the pressure of discharged air in reservoir 22 at a predetermined pressure, a dump or bypass valve 24 is employed to discharge compressed air from compressor 11 to the atmosphere when the predetermined pressure in the reservoir 22 is satisfied. Dump valve 24 may be operated either at a fully opened position or a fully closed position, or it may be modulated, according to the characteristics of the mode of operation employed. For example, dump valve 24 is modulated to maintain the desired pressure in reservoir 22 when the compressor is operating on base mode. When the compressor is operating on intermittent mode, the dump valve is either fully opened or fully closed.

For purpose of illustrating a preferred embodiment, the control system in accordance with our invention

comprises a plurality of pure fluid devices which are connected together to obtain the desired control of the system, whether the compressor is operating on base mode or on intermittent mode. However it should be specifically understood, the fluid devices may be replaced by their equivalent electrical, electronic or electro-pneumatic components, without departing from the scope of our invention, except in such cases where the utilization of such fluidic devices is claimed as being an essential feature of my invention.

The fluid devices of the control system are operated from a source of pressurized air, the source either being from the discharge line of compressor 11 (as shown) or from an external source (not shown) or from a combination of these two.

The pressure signal in the preferred embodiment is obtained from a point intermittent the compressor discharge and reservoir 22. The signal flows through conduit 30 through a first port 31 of valve 32 (see FIG. 2). Valve 32 is a two position valve, that is the valve will either pass the entire signal supplied thereto or will completely block the continued flow of the signal. The manner in which valve 32 is controlled shall be more fully explained hereinafter.

The signal passing through valve 32 is supplied to a plurality of main supply branch conduits, respectively 33, 34, 35 and 36. It should be understood that pressure regulators well known to those familiar in the art may be installed at desired locations in the various branch conduits to obtain desired control pressures therein.

INLET VALVE AND BYPASS VALVE REGULATION

Communicating with supply branch conduit 33 are supply lines 37 and 38 respectively of fluid amplifiers 39 and 40. Lines 37 and 38 provide a supply input signal of a pre-set magnitude to each of the amplifiers. As shall become apparent hereinafter, amplifier 39 provides a control signal to regulate the operation of inlet valve 19, and amplifier 40 provides a control signal to regulate the operation of bypass or dump valve 24.

Referring to FIG. 3, an enlarged view of the amplifiers and their associated components is illustrated for purposes of clarity. Amplifier 39 has a first control input 41 and a second control input 42. The signal transmitted to input 41 is supplied from main supply branch conduit 36, to a branch line 44. Line 44 has a first fixed resistor 43 and a variable resistor 41' disposed therein upstream from input 41. Controlling the magnitude of the signal supplied via line 44 is temperature sensing mechanism 46 which is provided to sense the temperature of the air passing through inlet line 18.

As is well known to those skilled in the art, as the temperature of the air increases it is desirable to increase the volume of air entering the compressor to maintain proper operating characteristics. Conversely, as the temperature of the air decreases it is desirable to decrease the volume of air passing to the inlet of the compressor. Temperature sensor 46 operates to selectively increase or decrease the magnitude of the control signal flowing to summing junction 42' and input 41, by selectively bleeding or closing off line 45 which is in communication with line 44.

Associated with second input 42 is summing junction 44'. Summing junction 44' has a plurality of control signals supplied thereto. A first control signal is sup-

plied to summing junction 44' via conduit 53. A second control signal is supplied to the summing junction via conduit 54. The manner in which the control signals are provided via conduits 53 and 54 shall be more fully explained hereinafter.

A third signal of a pre-set magnitude is supplied thereto via line 47, fixed resistors 48 and 49, and line 50.

A fourth control signal is supplied to summing junction 44' via line 52, having communication with inlet line 18. Line 52 is located downstream of the inlet valve. The pressure of the air entering the compressor thus provides a proportional control signal to summing junction 44'. As the pressure of the air in line 18 increases the control signal will also increase. Since valve 19 is generally throttled, the pressure in lines 18 and 52 is generally less than atmospheric.

Amplifier 39 includes a first output 57 and a second output 61. The control signal passing through output 57 is exhausted to the atmosphere through resistor 58. The control signal through output 61 passes through booster 62 and conduit 67 to regulate the operation of inlet valve 19. Booster 62 operates to increase the gain of the control signal by a predetermined amount. Booster 62 has a constant pre-set signal supplied thereto from conduits 63 and 64. Conduit 64 communicates with main supply branch 33. The magnitude of the control signal to valve 19 varies in accordance with variations in the control input signals passing through summing junctions 44' and 42'. The manner in which the input signals vary shall be more fully explained hereinafter.

Capacitors 65 and 66 are provided in lines 57 and 61 respectively to increase the stability of operation of amplifier 39 by providing a feedback signal to each of the summing junctions. Capacitor 65 is connected with summing junction 42' via line 59 and resistor 60; capacitor 66 is connected with summing junction 44' via line 68 and resistor 69.

Amplifier 40 has a predetermined supply signal provided thereto via line 38. Summing junctions 91 and 99 are associated with amplifier 40. Summing junction 99 has a predetermined control signal supplied thereto via conduit 94 which is in communication with supply branch 36. The signal flows in conduit 94 through a first resistor 95, and then passes into conduit 95' having a second resistor 98 disposed therein, into summing junction 99 from whence it passes to a first input 100 of amplifier 40. The control signal in conduit 94 also flows therefrom, through conduit 97, to a first three-way pneumatically operated relay 200. Variable resistor 96 is disposed between conduits 94 and 97 for a reason to be explained more fully hereinafter.

Summing junction 91 has a first input thereto via conduit 92. Conduit 92 is in communication with conduit 56, which receives an output signal from a second pneumatic relay 210.

Summing junction 91 has a second input thereto via line 120, which is in communication with conduit 90. Conduit 90 is disposed between the compressor discharge and the reservoir to provide a signal equal to discharge pressure. As the load on the compressor system increases, the pressure signal decreases due to the increased flow from the reservoir. Conversely, as the load decreases, the pressure signal will increase, due to the decreased flow from the reservoir and consequent

increase in "back pressure" resulting therefrom. Resistors 114 and 115 in conduit 90 make the signal passing to summing junction 91 proportional to discharge pressure.

Each of the summing junctions 91 and 99 have output signal feedback circuits similar to the feedback circuits of amplifier 39. The feedback circuit for summing junction 91 includes capacitor 105, conduit 106 and resistor 107. The feedback circuit for summing junction 99 includes capacitor 104, conduit 108 and resistor 109.

Amplifier 40 has a first control signal output 101 and a second control signal output 102 therefrom. Output 102 terminates in fixed resistor 103 which exhausts to the atmosphere.

Communicating with output 101 is booster 66 which is connected to conduit 64 via line 65. Booster 66 is similar to booster 62 heretofore described and operates to amplify the output signal delivered thereinto via conduit 101. Communicating with booster 66 is conduit 110. Conduit 110 communicates with conduit 112 which provides the control signal from the amplifier via conduit 101, to bypass valve 24.

Disposed between conduits 110 and 112 is solenoid valve 113 which has first and second operating positions. In a first position, the valve acts to communicate conduits 110 and 112; in its second position valve 113 operates to bleed all the pressure from the diaphragm of bypass valve 24 to place same in its normally open position. The manner in which valve 113 operates shall be explained more fully hereinafter.

Line 111 communicates with line 110 upstream of valve 113. Line 111 supplies the control signal delivered from amplifier 40 to a first port 221 of a third three-way pneumatic relay 220. Relay 220 includes spring 223 which operates to bias valve member 224 towards port 225. Relay 220 also includes port 226, which exhausts to the atmosphere. Valve 224 operates to either close port 225 to prevent any exhausting of a control signal provided through lines 233 and 234, or alternatively, operates to open port 225 to exhaust the control signal for a reason to be more fully explained hereinafter.

A predetermined control signal, provided through lines 36, 229, and 222, and resistor 228, provides an additional force to bias member 224 so as to prevent communication between ports 225 and 226. The variable control signal supplied via line 111 provides a force in opposition to the force supplied by spring 223 and the control signal from line 222, to move member 224 towards port 227 to thereby exhaust the control signal from line 234 through port 226.

Disposed upstream of the connection between line 229 and line 222 is resistor block 230. Resistor block 230 has a first line 231 and a second line 232 which communicate with line 229. Variable resistor 237 is disposed in line 232. The signal passing through line 232 and resistor 237 is exhausted to the atmosphere.

Disposed in line 231 is a second variable resistor 238. Line 231 is communicated via variable resistor 238 with line 239. Line 239 connects with switch 208 which has first and second operating positions depending upon the mode of operation of the compressor, i.e., whether the compressor is operating on either base or intermittent mode.

As shown, when switch 208 is in its dotted line position so that line 55' is in communication with line 239, the compressor is operating on base mode. Line 239 is

thus exhausted to the atmosphere via line 55'. When the compressor is operating on intermittent mode, switch 208 is placed in its solid line position so that line 55' is in communication with line 209.

The control signal in line 234 is provided via lines 233 and 290. The signal flowing through these two lines is also directed to line 235. Line 235 includes fixed resistor 236. Line 235 is connected to lines 229 and 232. Relay 220 operates to selectively exhaust the control signal of line 233 for a reason to be more fully explained.

Line 290 communicates line 233 with main supply branch 36. Line 290 has a resistor 291 disposed therein and terminates at valve 113 to regulate operation of the valve in a manner to be more fully explained hereinafter.

Line 201 communicates line 290 with first three-way pneumatic relay 200. Line 201 provides a predetermined control signal through port 203 to bias valve member 207 so port 205 is closed and ports 204 and 206 are in communication. Line 97 terminates at port 204. Spring member 202 provides an opposed biasing force to move member 207 towards port 204 to prevent communication between ports 204 and 206. When ports 204 and 206 are in communication, the control signal flows from line 97 to line 209 having variable resistor 209' disposed therein.

Line 209 terminates at switch 208. When switch 208 is in its intermittent mode of operation position, line 209 is communicated with line 55', to thereby exhaust the control signal in line 209 to the atmosphere.

Line 243 communicates line 290 with a fifth three-way pneumatic relay 240. The control signal supplied via line 143 operates to bias member 147 so as to close off port 242 of the relay. Opposing the force supplied by the control signal of line 243 is spring member 244. When the spring force exceeds the predetermined control signal force, member 247 is biased towards port 241 of the relay so as to communicate port 242 with port 248, thereby exhausting a control signal in line 249 to the atmosphere.

Line 249 has a predetermined control signal supplied thereto from line 292, which has a fixed resistor 293 disposed therein. Line 292 is in communication with main supply branch 36. The operation of relay 240 shall be more fully explained hereinafter.

SURGE PROTECTION

As is well known to those skilled in the art, it is desirable to protect the compressor during surge conditions. The control system in accordance with our invention achieves the desideratum by providing a plurality of interconnected components automatically operable to place the compressor in an unloaded state upon the occurrence of surge.

Line 286 is connected to the inlet of the third stage of the compressor and thus supplies a pressure control signal to lines 283, 284 and 285. Line 284 has a variable resistor 281 disposed therein. The signal supplied via line 284 is delivered to three-way pneumatic relay 270. The force supplied by the signal operates to move valve member 274 of the relay so as to communicate ports 277 and 278. Line 283 has a variable resistor 282 disposed therein and terminates by exhausting to the atmosphere.

Line 285 and line 405 supply the pressure signal to port 272 of relay 270. The signal supplied through port

272 provides a force in opposition to the force supplied by the signal through port 273. Spring 271 provides an additional opposing force. Spring 271 and the control signal force supplied through port 272 operate so as to keep valve member 274 in its solid line position so as to prevent communication between ports 277 and 278. Line 275 communicates port 277 with branch conduit 34 which has a predetermined control signal there-through.

When member 274 is placed in its dotted line position in a manner to be more fully explained hereinafter, the control signal from line 275 passes through port 277 to port 278 and line 266.

Line 266 communicates port 278 with port 265 of an additional three-way relay 260. Port 265 is selectively communicated with port 269 by the operation of valve member 264. When member 264 is in its solid line position, port 265 is in communication with port 269 so as to deliver the control signal supplied via line 266 to line 288 which in turn supplies the control signal to lines 287, 289 and 211.

Line 287 terminates in port 287' of relay 260. The control signal supplied thereto provides a force so as to move member 264 to its dotted line position.

Acting to bias member 264 in its solid line position is spring 267, and the force supplied via the control signal provided from line 261 through port 262.

When member 264 assumes its dotted line position, port 263 of relay 260 is in communication with port 269, thereby communicating lines 268 and 288.

Line 268 is in communication with conduit 34 so as to provide a predetermined control signal to line 288, and lines 287, 289 and 211 in communication therewith.

Line 289 delivers the control signal from line 288 to port 254 of three-way pneumatic relay 250. The signal provided thereby operates to bias valve member 252 of the relay towards its dotted line position. Opposing this is a force supplied by spring member 251. Spring member 251 operates to keep member 252 in its solid line position, whereby port 255 is in communication with port 253. When member 252 is biased to its dotted line position, port 255 is in communication with port 257'. Line 256 communicates port 255 with conduit 34 so as to supply a predetermined control signal thereto. When member 252 is in its solid line position, the control signal supplied via line 256 is passed to line 258 having resistors 259 and 259' disposed therein. This control signal is essentially exhausted through resistor 259' to the atmosphere. When member 252 is in its dotted line position, line 256 is in communication, via ports 255 and 257', with line 257, so the control signal is transmitted to indicator light 403.

The control signal supplied via line 211 is delivered to port 213 of three-way pneumatic relay 210. This control signal provides a force to move valve member 214 to its dotted line position. Spring 212 provides a force to bias member 214 towards its solid line position. When member 214 is in its solid line position, line 215 is communicated with the atmosphere via ports 216 and 217. When member 214 is in its dotted line position, port 216 is closed so as to prevent the control signal in line 215 from being exhausted to the atmosphere.

Line 215 communicates line 257 with line 56, to provide a control signal to lines 53 and 92 respectively. The control signal is provided to the amplifiers to posi-

tion the inlet and bypass valves in their normal positions when surge conditions have been detected. The operation of the surge detecting feature shall be more fully explained.

PROTECTION AGAINST UNDESIRABLE OPERATING CONDITIONS, EXCEPT SURGE

A further feature of the control system includes means to prevent the continued operation of the compressor when a potentially harmful condition exists. For example, severe damage may occur if the compressor is operated when the temperature of the lubricating oil exceeds a predetermined value, or if the pressure of the oil diminishes below a predetermined value, or if the temperature of the air that is being compressed exceeds a predetermined value at some point in the compression cycle.

The safety means of our control system comprise only fluidic devices. Heretofore similar safety means have included electro and electro-pneumatic components. Such devices are subject to wear and therefore require high maintenance costs. Sometimes, due to their relative inaccessibility, routine maintenance is eliminated, thereby creating a possibility that such devices may not function as required and resultant damage to the compressor may occur.

The fluidic devices in accordance with our invention are modular in construction and are easily removed from their mounting since a plug-in feature is included. Routing maintenance may then be readily conducted and if replacement of a module is required, such operation can be quickly conducted to reduce maintenance costs. In addition, the fluidic devices generally do not wear as quickly as other devices, thereby further reducing maintenance costs.

Main supply branch 35 provides a predetermined control signal to lines 411, 412, and 413, having communication therewith. The safety devices heretofore noted operate so during normal operation, the control signals supplied through lines 411, 412 and 413 are bled to atmosphere. When the condition detected against occurs, the particular safety device that senses same operates to prevent the bleeding of air through the particular line, for example the air temperature safety device operates to prevent bleeding of air from line 411 upon the temperature of the air increasing beyond a predetermined point. Line 411 communicates with line 348 and port 343 of a three-way pneumatic relay 340. Relay 340 includes a second port 344 having communication with line 349, which transmits a predetermined control signal therethrough from line 338. Variable resistor 339 is disposed in line 338.

Fixed resistor 414 is disposed in line 411. Relay 340 includes valve member 342 which when in its solid line position operates to communicate port 346 with port 347. The forces supplied by the predetermined control signal transmitted through port 344, and spring member 341, operate to maintain member 342 in its solid line position.

The force supplied by the control signal transmitted via line 348, through port 343, operates to move member 342 to communicate port 345 with port 347. Port 347 selectively exhausts the control signal from lines 359 or 359' to the atmosphere. Line 359 is in communication with line 357, which in turn is in communication with main supply branch 35. Line 357 is additionally in communication with port 353 of three-way

pneumatic relay 350. The force supplied by the control signal provided through port 353 operates to place valve member 356 of the relay into its dotted line position. Spring 351 acts in opposition to the control signal force to bias the member so that it is in its solid line position, thereby closing off port 354. When member 356 is in its dotted line position a predetermined control signal is supplied via line 358, and ports 354, 355 of relay 350, to lines 417 and 418. The control signal supplied via line 417 is delivered to indicator light 402. The control signal passing through line 418 is delivered via line 420 to port 32' of valve 32.

Devices 300, 310, 320 and 330, are identical in operation and structure to relays 340 and 350. Thus they need not be explained in detail. The devices are actuated in response to the occurrence of some other condition or conditions, such as those heretofore noted.

OPERATION

The manner in which the control system functions to regulate the operation of the compressor during normal operation and during certain adverse conditions will now be explained.

The regulation of inlet valve 19 in response to changes in the pressure and/or temperature of the ambient air entering the compressor will now be explained. The control of inlet valve 19 in accordance with the variations in the condition of the entering air is identical regardless of in which of the two modes of operation the compressor is operating.

As will be more apparent hereinafter, the control signals to summing junctions 44' of amplifier 39, supplied by lines 53 and 54 do not affect operation of the inlet valve in accordance with temperature and/or pressure variations in the inlet air. Accordingly, let us assume that there are no control signals being transmitted by either line 53 or line 54. Therefore, the only control signal passing to summing junction 44' is supplied via conduits 47 and 52.

In order to understand the operation of the amplifier 39, let us assume that one of the variables (pressure, temperature) of the air entering the compressor has remained constant and the other has changed. For example, let us assume that the pressure of the air entering the compressor has remained constant and the temperature thereof has varied.

Since pressure of the entering air is assumed to have remained constant, the control signal input transmitted to summing junction 44' and to input 42 of the amplifier also remains constant. If the temperature of the air increases, temperature sensor 46 operates to increase the magnitude of the control signal flowing in line 44 to summing junction 42' and to input 41. When the signal at input 41 exceeds the magnitude of the control signal at input 42, the supply input provided through line 37 is biased to a greater extent through output 61. There is a simultaneous decrease in the passage of supply air through output 57. By increasing the magnitude of the control signal flowing through output conduit 61 and thence through booster 62, where the output signal is amplified by having the predetermined control signal supplied via lines 63 and 64 combined therewith, a greater control signal is passed to the diaphragm of inlet valve 19. The increased magnitude control signal operates to further increase the inlet opening so that a greater volume of air is passed to the first stage of the compressor.

Conversely, if the temperature of the air decreases, temperature sensor 46 operates to decrease the magnitude of the control signal to input 41 of amplifier 39, thereby decreasing the magnitude of the control signal eventually passing to the diaphragm of inlet valve 19 so as to diminish the flow of air to the compressor.

Now let us assume that the temperature of the air remains constant and that the pressure of the air varies, for example, the pressure of the air increases. As the pressure increases, a proportional increase will occur in the control signal passing through conduit 52 which increases the control signal passing to summing junction 44' and input 42. The increased signal at input 42 biases the supply signal from conduit 37 so that a greater amount thereof flows through output 57 and to the atmosphere via resistor 58. A decrease in the magnitude of the control signal passing through output 61 will thus occur, which will in turn decrease the magnitude of the control signal transmitted via conduit 67 to the diaphragm of inlet valve 19, thereby modulating the valve to decrease the quantity of air passing to the compressor.

Conversely, if the pressure of the air were to decrease, an increased magnitude control signal will be felt at the diaphragm of inlet valve 19 to modulate the valve towards an increased opening position to increase the flow of air to the first stage of the compressor.

If both temperature and pressure of the air entering the compressor varies, amplifier 39 will operate to compare the changes and to produce a signal in output 61, which is proportional to the changes to properly position the inlet valve.

BASE LOAD OPERATION

The manner in which the bypass valve and inlet valve are regulated, depending upon the mode of operation, will now be explained. Assume that it is desirable to operate the compressor on base load so bypass valve 24 is modulated to maintain a constant discharge pressure. Switch 208 is therefore placed in its base load position so as to communicate line 239 with line 55'.

As noted hereinbefore, line 90 provides a control signal which is proportional to discharge pressure. Line 90 is communicated with summing junction 91 of control amplifier 40. As the discharge pressure increases the magnitude of the control signal increases. However, the signal is actually a negative input so that as the magnitude of the control signal increases, a decreased biasing force is presented at input 93. Conversely, as the discharge pressure decreases so as to decrease the magnitude of the control signal, which is proportional thereto, an increase biasing force will be presented at input 93.

The control signal supplied via line 94 and 95' provides a predetermined control signal to input 100 of amplifier 40, via summing junction 99. The magnitude of the control signal is regulated by the setpoint adjustment obtained via variable resistor 96.

Assume the discharge pressure has increased to decrease the biasing force at input 93. As the biasing force decreases, the magnitude of the control signal in output 102 increases, with a concurrent decrease in the magnitude of the signal in output 101. The decreased magnitude control signal is transmitted from output 101 to booster 66 where the signal is amplified. The signal then passes through line 110, valve 113 and line 112 to the diaphragm of bypass valve 24. The decrease

in the magnitude of the control signal biases the valve toward its normally open position, thereby increasing the flow of air to the atmosphere to decrease the discharge pressure as is desired.

Conversely, if the discharge pressure decreases below the predetermined value, as determined by the signal to input 100, the change in force acting on the supply input signal provided by line 92, will increase the magnitude of the signal at output 101 and decrease the signal at output 102. The increased magnitude signal is transmitted to the diaphragm of valve 24 to modulate same to a more closed position to increase the discharge pressure as desired.

If the load on the system served by the compressor is substantially decreased, the bypass valve will approach a fully open position to exhaust almost the entire output of the compressor to the atmosphere. Continued operation of the compressor in its normal fashion decreases the machine's efficiency by increasing the operating cost, which may be substantial if the load on the system remains small for a prolonged period of time. Therefore, one of the essential features of the control system is to provide means for automatically placing the compressor in an unloaded state during base mode operation when a pre-selected rate of bypass has occurred.

As noted hereinbefore, the control signal supplied to the diaphragm of bypass valve 24 is also transmitted through line 111 to control relay 220. As the control signal decays due to an increase in the discharge pressure, the predetermined control signal provided by line 229 through port 228' and spring 223 operate to move member 224 so as to close off port 225. Until port 225 is closed by operation of member 224, the control signal supplied through line 234 is exhausted via port 226. Line 234 communicates with line 233 and thus with line 290. Resistor block 230 having variable resistors 237 and 238 operates to continuously exhaust a portion of the control signal from line 233 through lines 235, 231 and 232. Since the compressor is operating on base load, variable resistor 238 is exhausted to the atmosphere via line 239 and line 55'. By continuously exhausting a portion of the control signal to the atmosphere, the magnitude of the signal transmitted via line 229 to port 228' is limited. It is therefore only upon a substantial decay in the control signal provided by line 111, as a result of a large decrease in the load on the compressor, that member 224 is actuated to close port 225. With port 225 closed by member 224, less bleeding of the control signal transmitted by line 233 occurs, thereby increasing the magnitude of the control signal in line 290.

A concurrent increase occurs in the control signal supplied via line 243 to port 246 of relay 240. The increased control signal operates in opposition to the force supplied via spring 244 to move member 247 to its dotted line position so as to close off port 242. Heretofore, with member 247 in its solid line position, the control signal supplied from main supply branch 36 and line 292 to line 249 has been bled via ports 242 and 248. With port 242 closed, the control signal in line 249 is transmitted to line 54 having communication with summing junction 44' of amplifier 39. The increased biasing force thus placed on the supply signal, eliminates the signal through output 61, to place inlet valve 19 in its unloaded or normal position, that is, fully closed.

Additionally, the control signal in line 290 is passed to valve 113 so as to place same in its second operating position, whereby the control signal from line 110 is prevented from passing to line 112. In addition, the control signal already operating on the diaphragm of bypass valve 24 is exhausted to the atmosphere, thereby placing the valve in its normally open position so the compressor is fully in an unloaded state.

Thus, it is apparent that with the novel control system, the control automatically operates so as to place the compressor in an unloaded state when the machine is operating on base mode and the discharge pressure has exceeded a predetermined magnitude due to a substantial decrease in the load on the machine. This results in a substantial saving in operating costs. When the load on the machine increases thereby decreasing the discharge pressure, the control automatically operates to place the compressor in normal base mode operation.

It should be noted with switch 208 in its base load position, line 209 is effectively blocked, thereby making relay 200 inoperative during base load operation.

INTERMITTENT LOAD OPERATION

Assume now instead of operating the compressor on base mode the machine is operating on intermittent mode. For such operation, the compressor is operated in an unloaded state except when the discharge pressure falls below a minimum predetermined point. Switch 208 is placed in its intermittent mode position, communicating line 209 with line 55', and preventing any exhausting of air through resistor 238 and line 239. Thus there is an increased biasing force placed on member 224 to maintain same in its dotted line position, due to the increased control signal supplied to port 228' via line 222.

As is apparent, it will only require a small decay in the control signal supplied via line 111 to port 221 for member 224 to assume its dotted line position so as to close port 225. With port 225 closed, the control signal supplied via line 290 is increased very rapidly in the same manner as heretofore explained for base mode operation.

The signal is transmitted from line 290, via line 201, to actuate valve member 207, to switch it to its dotted line position thereby communicating ports 204 and 206. The signal transmitted via line 97 is thus exhausted to the atmosphere through line 209, valve 208 and line 55'. By immediately exhausting the predetermined control signal provided to summing junction 99 of amplifier 40, the amplifier senses a "false" excessively high discharge pressure due to the complete absence of any predetermined control signal. By sensing the "false" excessive discharge pressure, the supply signal is biased completely to output 102, to thereby remove any pressure from the diaphragm of bypass valve 24, to place same in its normally open position. The manner in which inlet valve 19 is placed in its normally closed position is the same as heretofore explained for base mode operation.

SURGE PROTECTION OPERATION

The manner in which the control system operates to protect the compressor during surge conditions will now be explained.

Line 286 communicates line 283, 284 and 285 to the inlet of the third stage of the compressor. If surge oc-

curs, the pressure in line 285 decreases rapidly during each cycle of reverse flow of air through the compressor. However, such rapid decrease of pressure will not occur simultaneously in conduit 284 due to having resistor 281 disposed therein, thus a pressure differential is established between ports 272 and 273 of relay 270. Due to the high pressure at port 273, member 274 will move to its dotted line position, opening up port 277 to communicate line 275 with line 266 via port 278. Line 266 communicates with port 265 of relay 260, thus the predetermined control signal transmitted from conduit 34 flows through ports 265 and 269 to lines 287, 288, 289 and 211. By providing the predetermined control signal to line 287, valve member 264 of relay 260 moves to its dotted line position, thereby opening port 263 to communicate line 268 with line 288. By communicating lines 268 and 288, the control system is locked into its surge detecting state until otherwise reset by means to be more fully explained hereinafter.

The predetermined control signal from line 288 passes into line 289 having communication with port 254 of relay 250. This predetermined control signal supplies a force of a sufficient magnitude to cause valve 252 of the relay to move to its dotted line position, to communicate line 257 with port 255 of line 256. Until valve member 252 is so actuated, line 256 and port 255 have been in communication with port 253 and line 258 having resistors 259 and 259' disposed therein. Resistor 259' exhausts the predetermined control signal of line 256 to the atmosphere.

When valve 252 closes port 253, the predetermined control signal is transmitted by line 257 to indicator light 403, to actuate same to indicate a surge condition has occurred.

The predetermined control signal from line 268 additionally passes to line 211 having communication with port 213 of relay 210. The predetermined control signal supplies a force to cause valve member 214 to move to close port 216, to prevent the signal in line 215 from being exhausted to the atmosphere. Line 215 is in communication with line 257 so the control signal transmitted by line 257 is also transmitted by line 215 to line 56 in communication therewith. Line 56 is in communication with line 53 which provides the predetermined control signal to summing junction 44' of amplifier 39. By providing the predetermined control signal to the summing junction, the supply signal thereto is biased towards output 57 to eliminate the control signal from the diaphragm of inlet valve 19 so as to place same in its normally closed position.

Line 56 is also in communication with line 92 which communicates with summing junction 91 of amplifier 40. By providing the predetermined control signal to summing junction 91, which as noted hereinbefore provides a negative input to the amplifier, the supply control signal provided through line 100 is biased towards output 102. The control pressure acting on the diaphragm of valve 24 is eliminated to place the valve in its normally open position. When surge occurs, the compressor is placed in an unloaded state to prevent any damage to the compressor.

In order to take the compressor out of its unloaded state, an operator has to manually push reset valve 370 to communicate line 30 with line 371. The predetermined control signal thus passes through resistor 372 to lines 373 and 261, communicating with port 262 of relay 260. The predetermined control signal supplies a

force, to assist the spring force, to move valve 264 to close port 263.

With port 263 closed, the predetermined control signal is prevented from passing from line 268 to lines 287, 288, 289, and 211. Thus, if a surge condition no longer exists, there will be no pressure signal provided through line 266 so the operation of the compressor may return to normal, and the inlet and bypass valves will be operated as heretofore explained, depending on the mode of operation.

OPERATION UPON THE OCCURRENCE OF AN UNDESIRABLE OPERATING CONDITION, OTHER THAN SURGE

The manner in which the components of the control system operate to effectively discontinue operation of the compressor when a potentially harmful condition occurs will be now explained.

As noted hereinbefore, the sensing devices installed to detect the occurrence of some unwanted condition operate, when in their normal state, so as to bleed lines 411, 412, and 413. Let us assume the air temperature of the compressed gas at some particular point, such as downstream of the intercooler (not shown) between the second and third stages has exceeded a safe value. The particular sensing device operates to close the bleed port of line 411. Line 411 is in communication with main supply branch 35. When the bleed port of line 411 is closed, a predetermined control signal is supplied from line 35, via line 411, to line 348 and port 343 of relay 340. The force provided by the control signal operates to move valve member 342 so as to open port 345 in line 359' and to close port 346 in line 359. Before the actuation of the valve from its solid line position, port 346 has been in communication with port 347 so as to exhaust the signal in line 357, transmitted thereto from line 35. By opening port 345, to communicate same with exhaust port 347, the control signal previously supplied port 344, from lines 349 and 359', is exhausted to the atmosphere, thereby diminishing the force acting in opposition to the force supplied by the control signal delivered through port 343.

By closing port 346, the predetermined control signal in line 357 is supplied to port 353 of 350. The force supplied by the predetermined control signal operates to actuate valve member 356 to move same towards port 354'. Simultaneously port 354 in line 358 is uncovered to provide a predetermined control signal therefrom to port 355.

The predetermined control signal then flows through lines 417 and 418. Line 418 has a check valve disposed therein to permit flow only from port 355 to line 420 in communication with line 418. The control signal thus provided passes to port 32' of air operated valve 32 so as to actuate the valve to prevent any flow from line 30 to line 33 in communication therewith. By eliminating any control air, the inlet and bypass valves are placed in their normally closed and open positions respectively.

In addition, the control signal may be supplied to a fluidic pressure switch (not shown) in the electrical circuit of the prime mover, to stop the prime mover. Valve 32 is so formed that once it has been placed in either of its two operating positions, it does not change position until a positive force is exerted on its opposed port. For example, even if the temperature of the air diminishes to normal, the compressor may not be re-

started until an operator manually resets the valve so as to permit communication between lines 30 and 33. It is thus apparent that the compressor fails safe, that is any operation of the compressor is completely prevented once an unwarranted condition has occurred, 5 thereby eliminating any possible human error.

Line 417 provides the control signal to a particular indicator light to indicate the source of trouble. The control signal is then exhausted via line 371 which includes resistors 372 and 382. Resistor 382 exhausts 10 substantially all of the control signal to the atmosphere. Any control signal supplied via lines 417 and 371 to port 32" is not of sufficient magnitude to move the valve to communicate lines 30 and 33.

When the operator wishes to restart the compressor, reset valve 370 is moved from its normally closed position, to a position so as to communicate line 30 with line 371, thereby placing a sufficient control signal on port 32" of valve 32 so as to move same to its open position, whereby lines 30 and 33 are communicated. 15 Normal operation of the compressor may then be resumed.

The novel control system herein disclosed effectively prevents operation of the compressor during conditions which may render any further operation unsafe to the compressor. In addition, the novel control system effectively operates the compressor so as to provide a more efficient operation to reduce the operating costs of the compressor.

While we have described and illustrated a preferred embodiment of our invention, it will be understood that the invention is not limited thereto but may be otherwise embodied within the scope of the following claims.

We claim:

1. A control system for automatically placing gas compression apparatus in an unloaded state during base mode operation, when the load on said compression apparatus has decreased below a predetermined level, said compression apparatus, including a gas compressor, an inlet conduit, valve means governing flow of gas through the inlet conduit to the compressor, means for storage of gas delivered by the compressor, discharge means connecting the compressor and the storage means, and bypass valve means for venting the discharge of the compressor to the atmosphere comprising: 45

- a. means for sensing the pressure of the gas flowing through said discharge means and for creating a first signal related to said discharge pressure; 50
- b. means for receiving a first signal of a predetermined magnitude and said signal relating to said discharge pressure and transmitting a resultant control signal;
- c. first means for receiving said resultant signal and operable to modulate said bypass valve means to maintain a substantially constant discharge pressure; 55
- d. second means for receiving said resultant control signal and operable when the magnitude of said signal has reached a predetermined value due to the load on said compression apparatus having decreased below a predetermined level to send a second control signal to cause said bypass valve means to assume a fully open position and to further cause said inlet valve means to assume a fully closed position; and 60

e. means operable to prevent said first resultant control signal from being transmitted to said bypass valve means when said second control signal is being transmitted, said bypass valve means thereby being maintained in a fully open position so long as the load on said compression apparatus remains below said predetermined level.

2. A control system in accordance with claim 1 wherein said last mentioned means includes valve means having first and second operating positions, said valve means transmitting said first resultant control signal when in its first operating position and being further operable to exhaust any signal from said bypass valve means when in its second operating position, said valve means being placed in its second operating position upon transmission of said second control signal. 15

3. A method of regulating the operation of gas compression apparatus operating on base mode, whereby said apparatus is automatically placed in an unloaded state when the load on the apparatus has decreased below a predetermined level, said apparatus including a gas compressor, an inlet conduit, a valve governing the flow of gas through the inlet conduit to the compressor, means for storage of gas delivered by the compressor, discharge means connecting the compressor and storage means and bypass valve means for venting the discharge of the compressor to the atmosphere comprising: 20

- a. sensing the pressure of the gas flowing through the discharge means; 30
- b. generating a first signal relating to said sensed discharge pressure;
- c. receiving the signal relating to said discharge pressure and comparing same to a signal of a predetermined magnitude to produce a resultant control signal; 35
- d. transmitting the resultant control signal through a first flow path to modulate the bypass valve means to maintain a substantially constant discharge pressure; and 40
- e. transmitting the resultant control signal through a second flow path, when the magnitude of said resultant signal has reached a predetermined value due to the load on the compression apparatus having decreased below a predetermined level whereby a second control signal is generated to cause said bypass valve means to assume a fully open position and said inlet valve means to assume a fully closed position, said bypass and inlet valve means being maintained in said positions until the load on said compression apparatus has increased above said predetermined level. 45

4. The method in accordance with claim 3 further comprising the step of blocking the transmission of the resultant control signal through said first flow path when the magnitude of the signal has reached the predetermined value. 55

5. A control system for automatically placing a gas compression apparatus in an unloaded state during base mode operation when the load on such compression apparatus has decreased below a predetermined level, said compression apparatus including; a gas compressor, an inlet conduit, valve means covering flow of gas through the inlet conduit to the compressor, means for storing gas delivered by the compressor, discharge means connecting the compressor and the storage means, and bypass valve means for venting the dis- 65

charge of the compressor to the atmosphere comprising:

- a. means for sensing the magnitude of the load on said gas compression apparatus;
- b. means for generating a first control signal, the magnitude thereof varying in response to changes in said load;
- c. means for receiving said first control signal and being operable to generate a resultant control signal, the magnitude thereof varying in response to changes in load on said compression apparatus; and
- d. means operable to receive said resultant control signal, when the load on said compression apparatus has decreased below a predetermined level, the magnitude of said resultant control signal being at a value whereby said resultant signal receiving means is operable to place said compression apparatus in an unloaded state wherein the inlet valve means is closed and said bypass valve means is open, thereafter when the load on said compression apparatus has increased above said predetermined level, the magnitude of said resultant control signal will vary whereby said resultant signal receiving means is further operable to place said bypass and inlet valves in their loaded base mode states.

6. The method of placing gas compression apparatus

operating on base mode in an unloaded state when the load on such compression apparatus has decreased below a predetermined level, said compression apparatus including; a gas compressor, an inlet conduit, valve means governing flow of gas through the inlet conduit to the compressor, means for storing the gas delivered by the compressor, discharge means connecting the compressor and the storage means, and bypass valve means for venting the discharge of the compressor to the atmosphere comprising the steps of:

- a. sensing that the load on said compression apparatus has fallen below a predetermined level;
- b. regulating the bypass valve means so it is placed in a fully open position and the inlet valve means so it is placed in a fully closed position when the decrease in the load has been sensed, to place the compression apparatus in an unloaded mode of operation;
- c. maintaining the inlet and bypass valves in their unloaded mode so long as the load on said compression apparatus remains below the predetermined level; and
- d. sensing that the load on said compression apparatus has increased above said predetermined level to thereby place said valves in their loaded base mode states.

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